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Title: Detectors and Data

Author(s): Karpius, Peter Joseph
Cutler, Theresa Elizabeth
McKenzie, George Espy IV
Stinnett, Jacob
Stults, Katrina Ann

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Detectors and Data

Pete Karpius, Theresa Cutler, Geordie McKenzie, Jacob Stinnett, Katrina Stults

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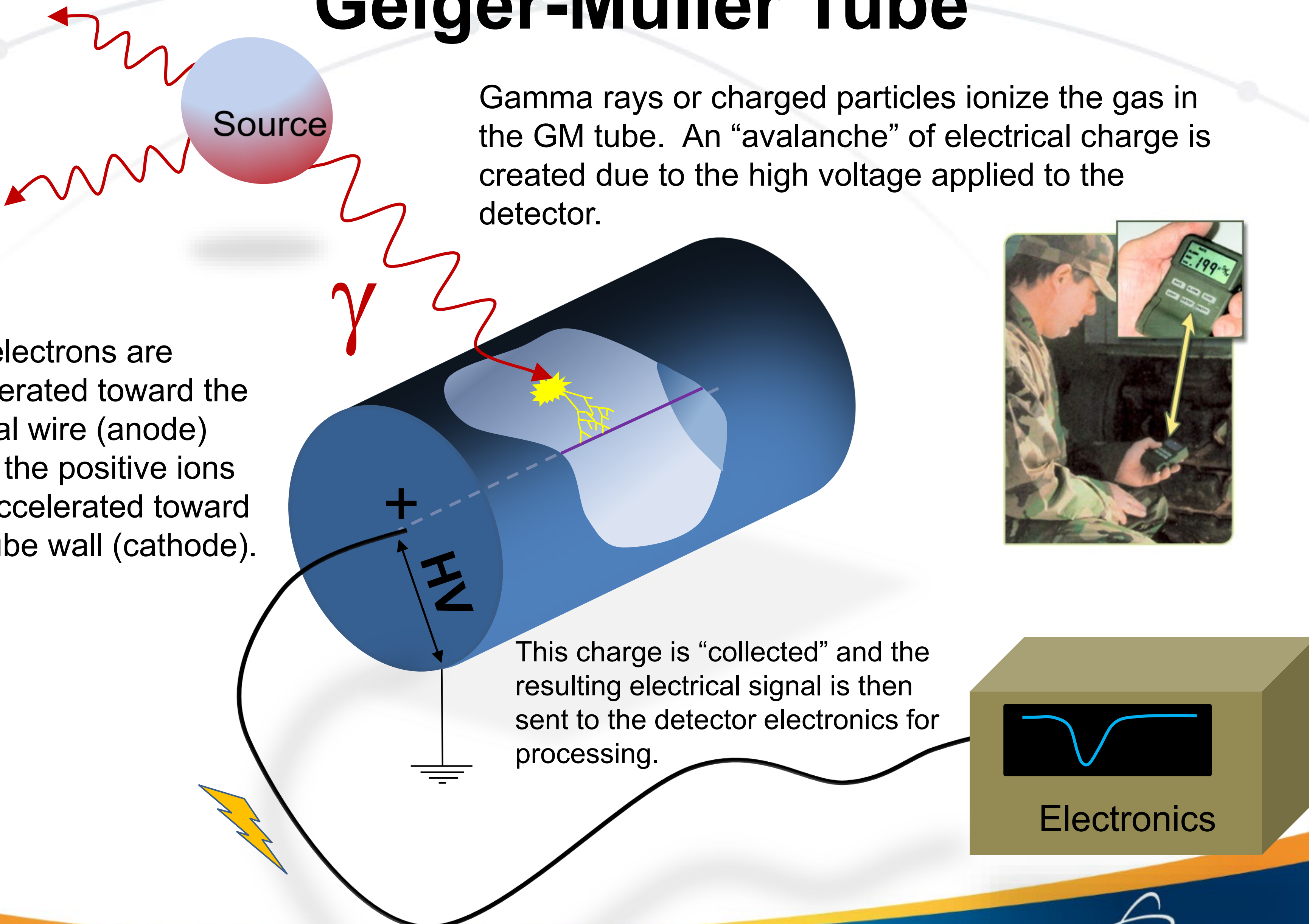
Outline

- Give 2 descriptions of a gamma-ray spectrum
- Describe the effect of shielding on a spectrum
- Explain ‘high-resolution’ (e.g. of HPGe)
- Contrast too little with too much moderator for measuring neutrons with ^3He

Geiger-Müller Tube

Gamma rays or charged particles ionize the gas in the GM tube. An “avalanche” of electrical charge is created due to the high voltage applied to the detector.

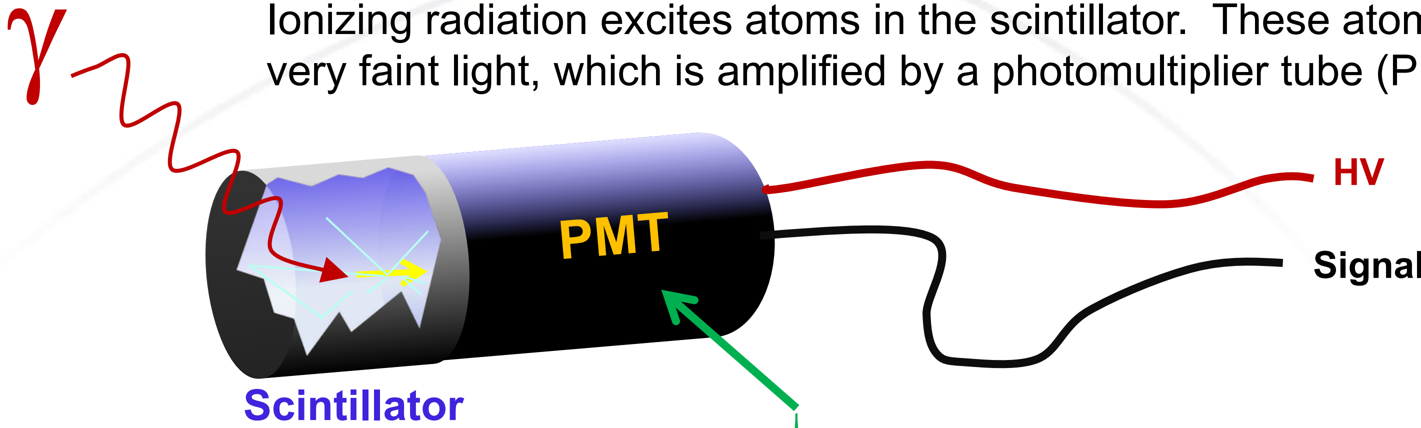


The electrons are accelerated toward the central wire (anode) while the positive ions are accelerated toward the tube wall (cathode).

This charge is “collected” and the resulting electrical signal is then sent to the detector electronics for processing.

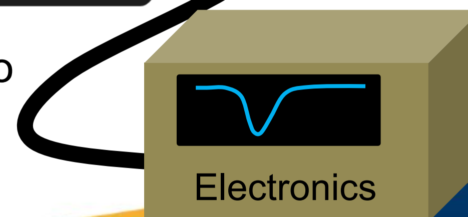
Scintillator & Photomultiplier Tube

Ionizing radiation excites atoms in the scintillator. These atoms emit very faint light, which is amplified by a photomultiplier tube (PMT).



Light from the scintillator is converted to electrons by the PMT and amplified a million times or more through a succession of electrodes called ‘dynodes’.

The resulting electrical signal is then sent to the detector electronics for processing.

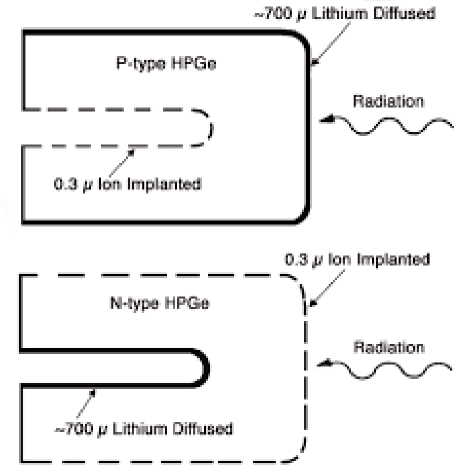


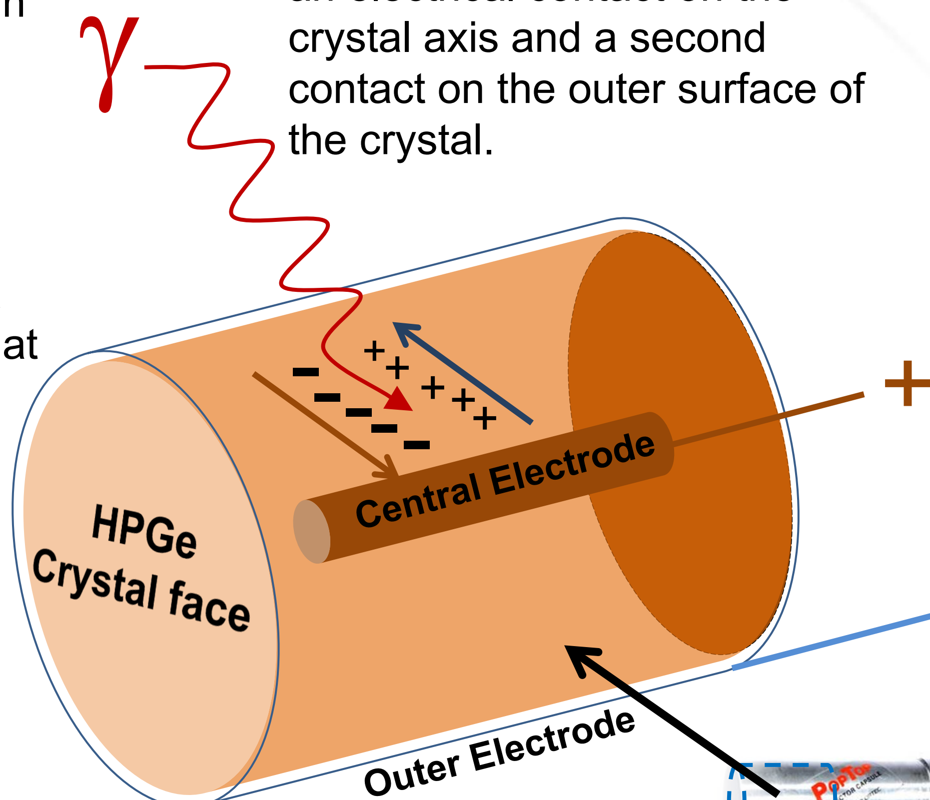
ID: High-Purity Germanium (HPGe)

Gamma rays create "electron – hole" pairs in the detector crystal.

When high-voltage is applied, electrons are collected at one contact and holes are collected at the other contact.

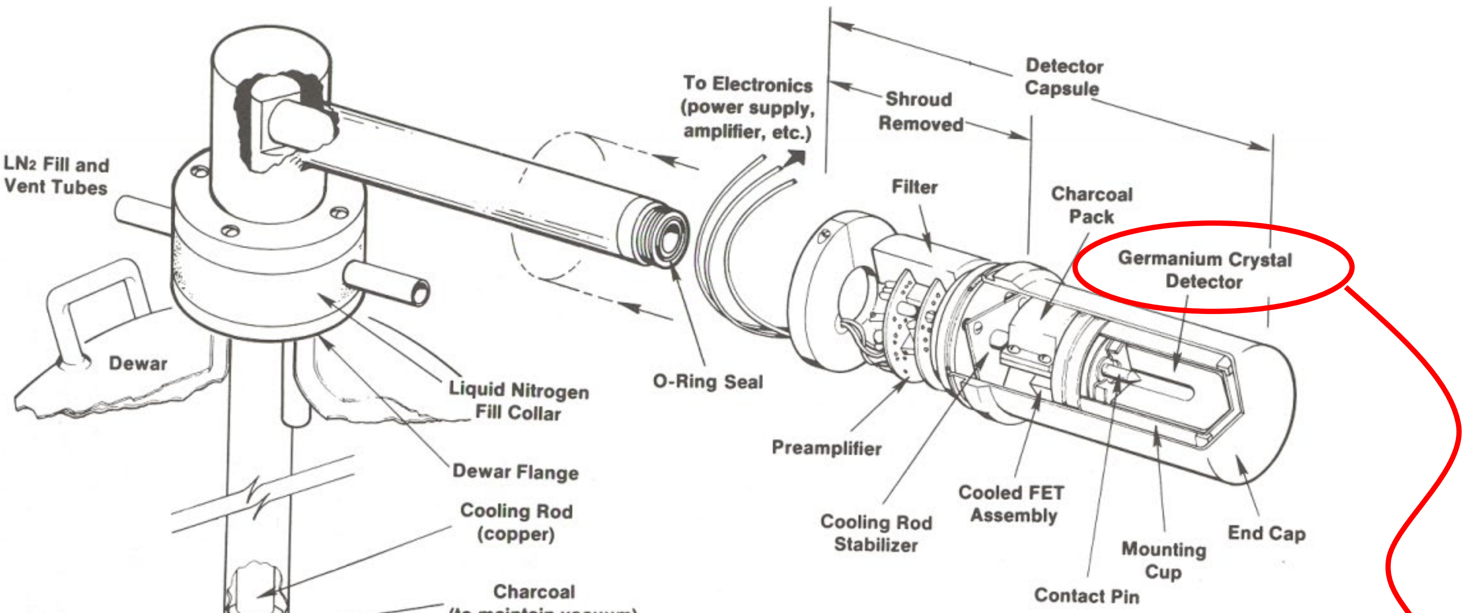
A coaxial HPGe detector has an electrical contact on the crystal axis and a second contact on the outer surface of the crystal.





HPGe detectors must be cooled mechanically or with liquid nitrogen

LN2-Cooled HPGe Schematic



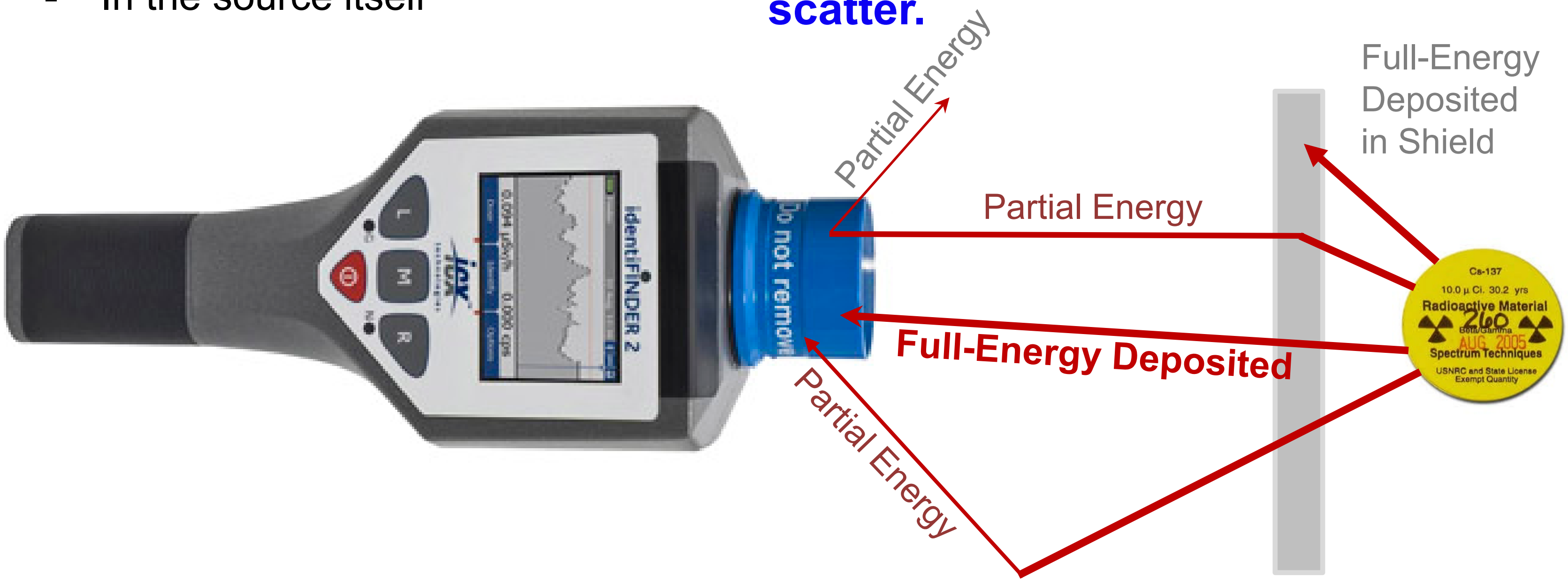
Coaxial HPGe Crystal

Gamma-Ray Energy Deposition

Gamma rays scatter everywhere:

- In the detector
- In the surroundings
- In the source itself

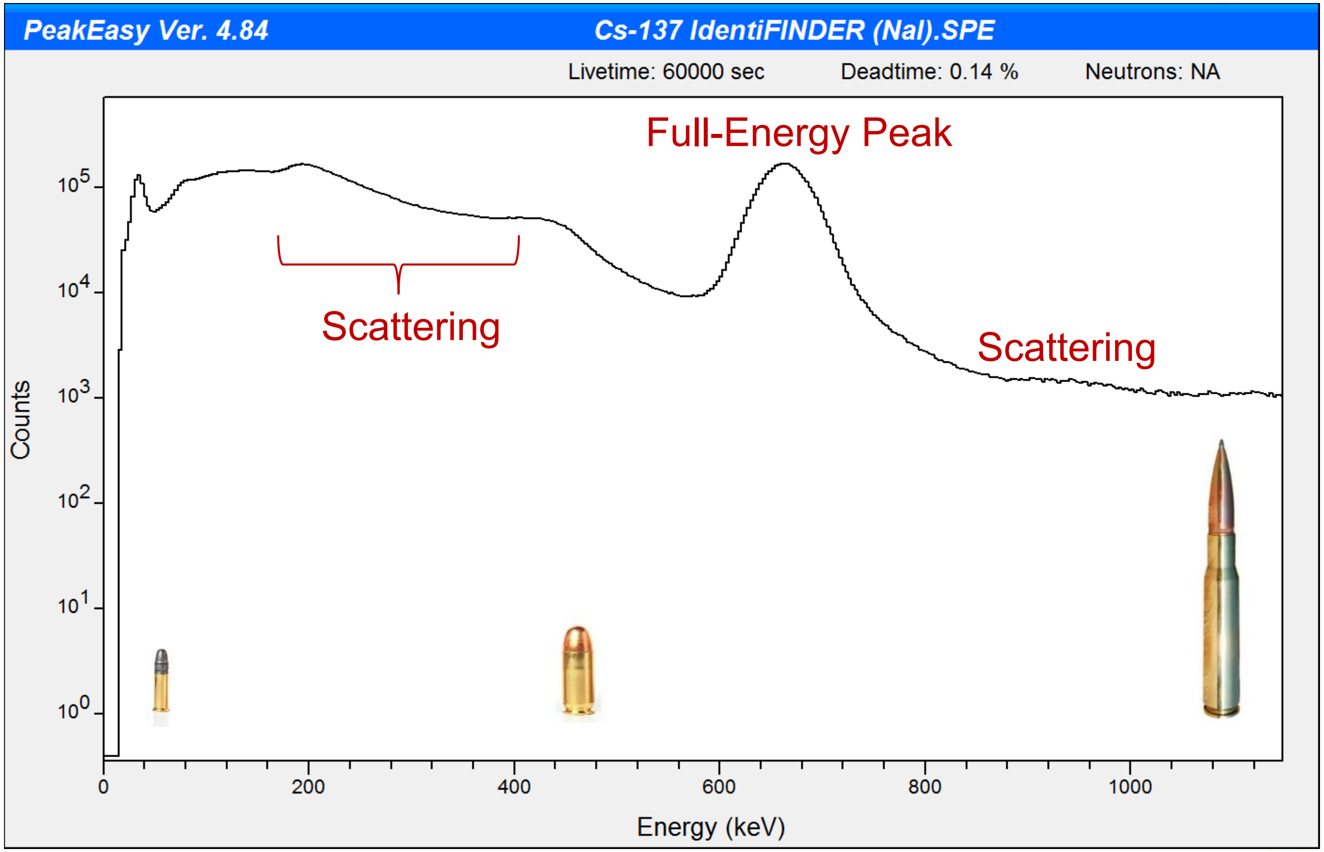
Gammas lose energy each time they scatter.



It is the full-energy deposition that is most valuable to us.

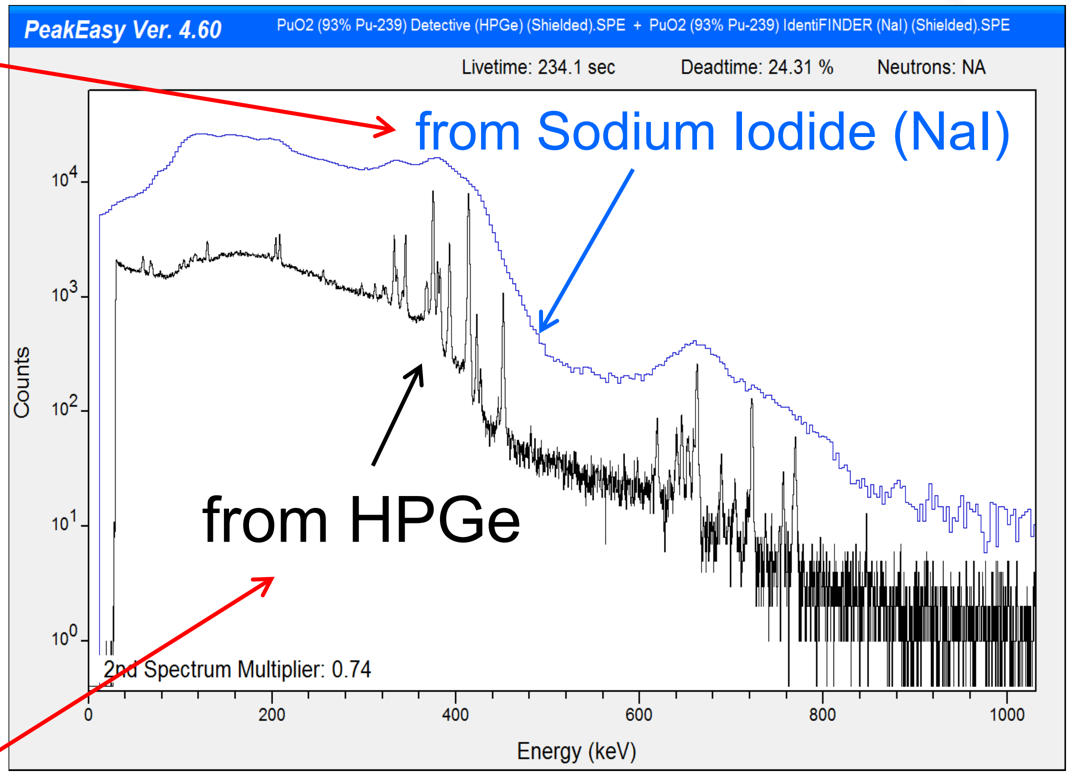
What is a Spectrum?   Part I

A gamma-ray spectrum is just a *histogram* of energy deposited in the detector.



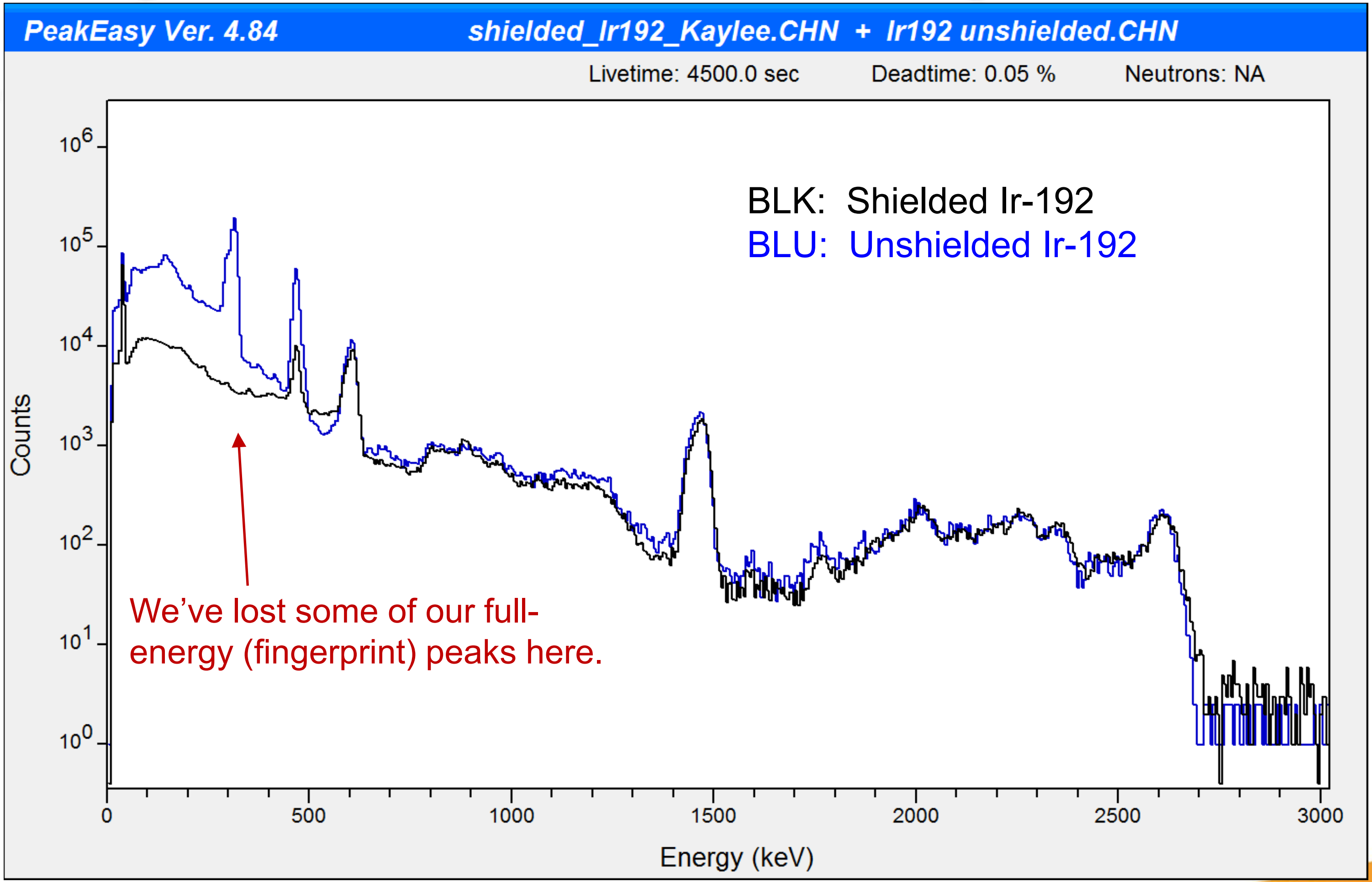
What is a Spectrum?   Part II

A spectrum is like a fingerprint.



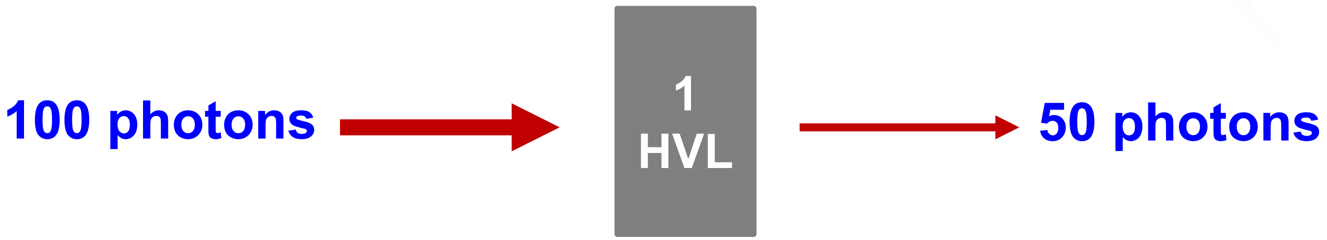
You get a better fingerprint with HPGe

The Effect of Shielding on a Spectrum



Half-Value Layers

A half-value layer (HVL) is the amount of material required to reduce the radiation intensity <u>at a specific energy</u> by ½.



Energy [keV]	H2O [cm]	Fe [cm]	Pb [cm]	U [cm]
60	3.4	0.070	0.012	0.005
186	5.0	0.6	0.05	0.025
414	6.6	1.0	0.3	0.14
1001	9.8	1.5	0.9	0.5
2614	16.2	2.3	1.4	0.8

Rule of Thumb to Kill the Signal

What if we use 10 half-value layers?

Transmission, T, through one HVL is 1/2

$$T^{10} = \left(\frac{1}{2}\right)^{10} \cong \frac{1}{1000}$$

Only one photon out of a thousand gets through 10 HVLs. For all practical purposes, we can consider these photons COMPLETELY SHIELDED. **So 10 HVLs effectively kills the signal.**

Note: This is only a convention! Others may use 5 HVLs.

Example: How much to shield ^{235}U?

As an example let's look at what it takes to totally shield the main, direct gamma-ray signature of ^{235}U, that is the peak at 186 keV.

- To kill the main ^{235}U signal you need:
  - Water: ~ 50 cm
  - Fe: ~ 6 cm
  - Pb: ~ 0.5 cm
  - U: ~ 0.25 cm

High Z and High Density

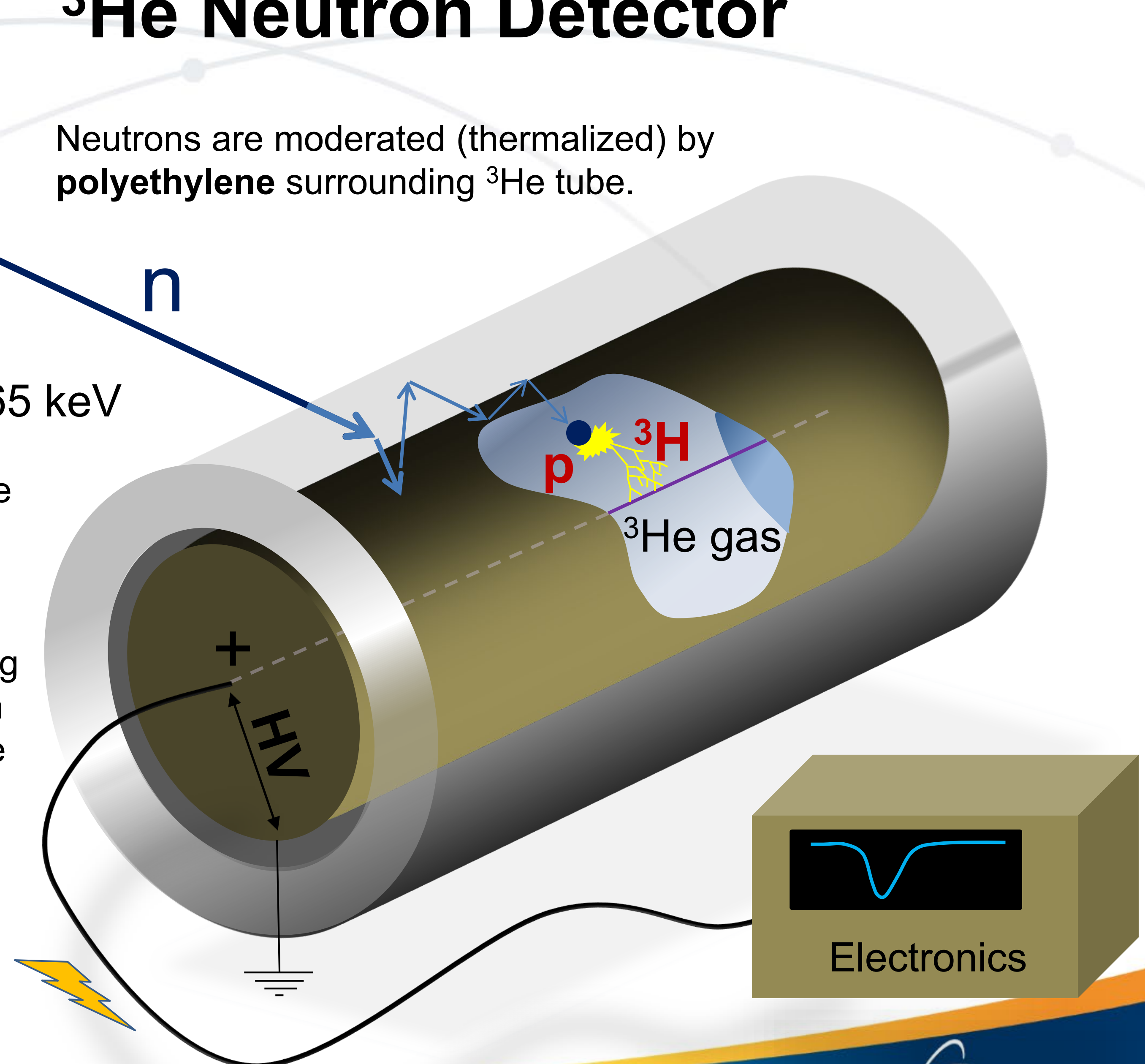
If you surround HEU with more than 2.5 mm of DU, the only direct ^{235}U gamma rays that you will see will come from the DU itself.

^{3}He Neutron Detector

Neutrons are moderated (thermalized) by **polyethylene** surrounding ^{3}He tube.

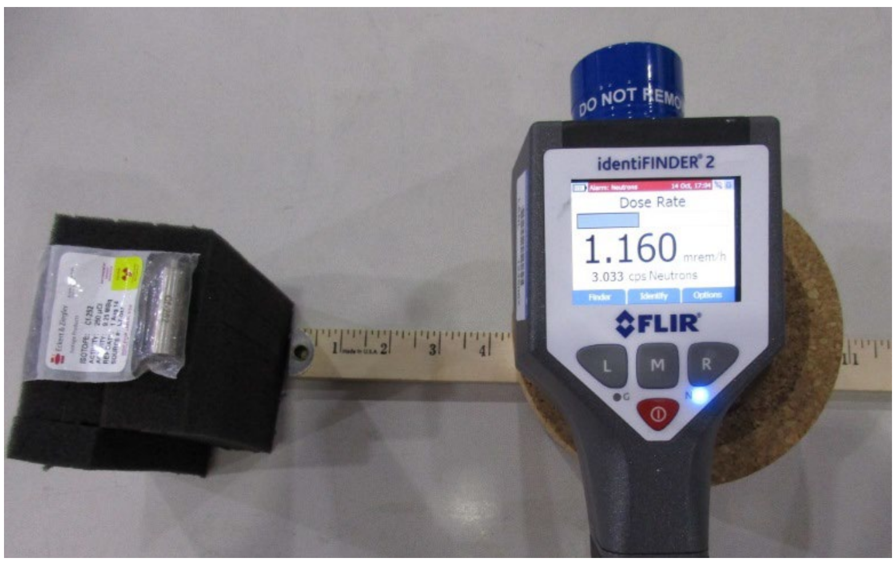
$^3He + n \rightarrow {^3H} + p + 765\ keV$

These thermal neutrons are captured by ^{3}He nuclei and produce tritium (**^{3}H**) and protons (**p**), which in turn ionize the gas. The resulting electrons and ions are then collected at the central wire and tube wall.

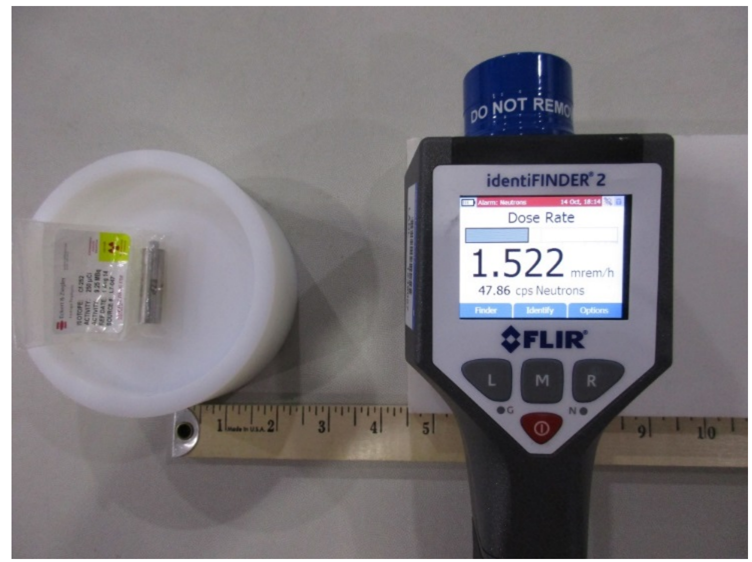


Effect of Moderator

Neutron Rate at 4.5" on foam block above table: ~ 3 cps



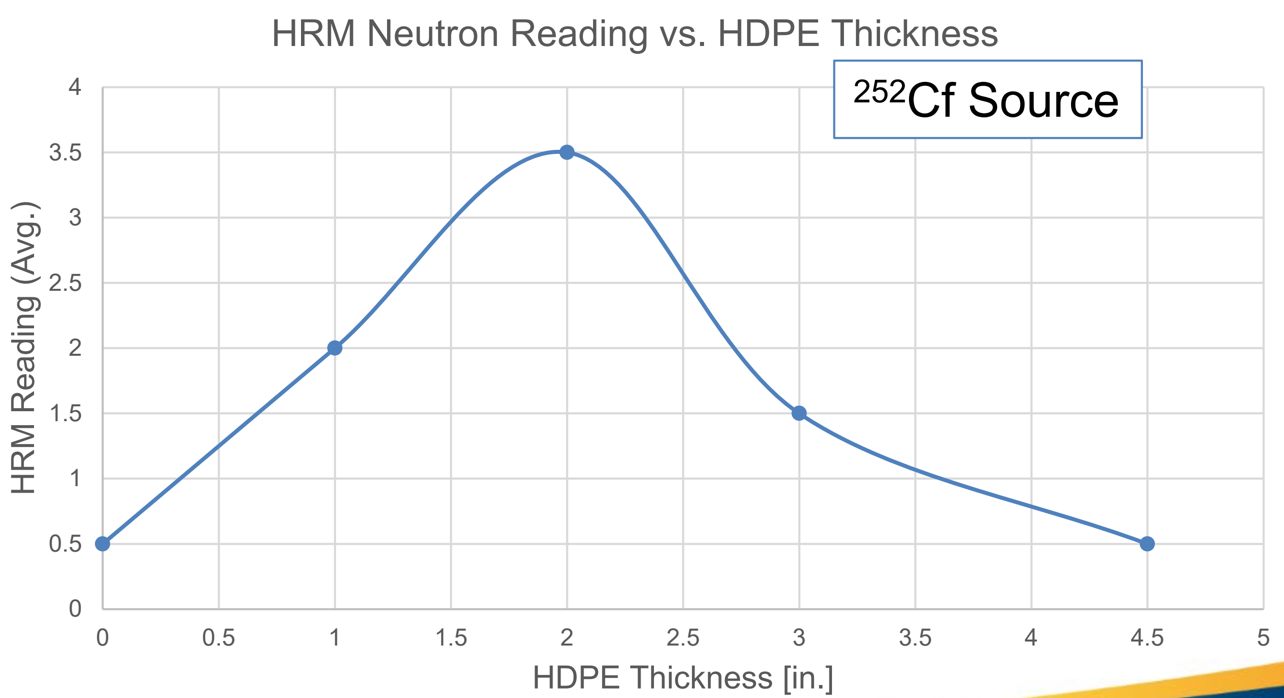
Neutron Rate at 4.5" with source and detector sitting on HDPE: ~ 48 cps



The source and distance are the same in both cases, the rate with the poly is > 10 times the rate without.

Under – to – Over Moderation

- At some point the system will become overmoderated and the measured count rate will go down
  - Neutrons with too little energy get captured by the moderating material itself before reaching the detector



Neutron Reflection

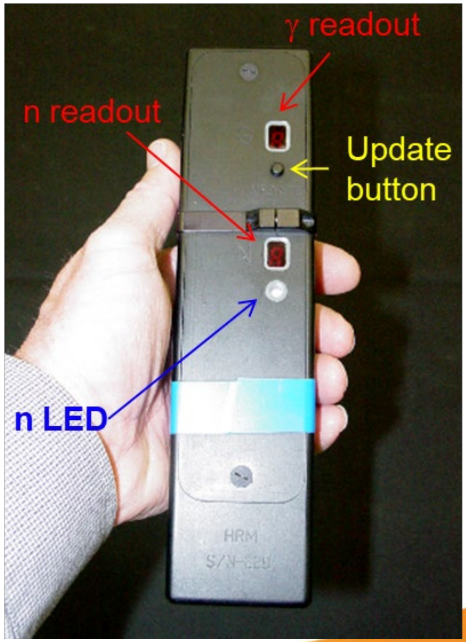
- Neutrons can be reflected back into the source
  - By the floor, walls, etc.
  - Materials around the source
  - People
- For a ^{3}He detector:
  - We *need* to thermalize (moderate) neutrons to measure them
  - Unlike gammas, we lose all information about the initial neutron energy
  - Therefore we can't tell if a neutron came directly from the source or was reflected into the detector by the environment (room return)

Search & ID Instruments

- Large area search
- Finding the hotspots
- Material Identification

Search Instruments: HRM

- HRM: Used for search and localization of gamma and neutron sources
  - ¾” x 5” ^{3}He tube + 1½” x ½” CsI crystal + PMT
  - Red LED readout (1-9) for γ and n.
  - Blue LED for neutron (one flash per detected neutron)
  - Normal neutron rate ~ 2-4 counts/min
  - Audio + silent (vibrate) notification
  - Background update
    - max at 12 mR/hr gamma



Search Instruments: LRM

- LRM: Wide-area search for neutron or **gamma** sources
  - Composed of HRM-type gamma and neutron detectors in series
    - 18 HRM gamma detectors
    - 9 HRM neutron detectors
    - Standard config: γ-n-γ … etc.
      - Based on cargo-container ships
    - Can be used in ‘totalize’ or ‘linear’ mode
  - LCD display (1-9) for γ and n readouts
  - 45-second history is displayed

Example Instruments for Nuclide ID

- IdentiFINDER R400 (NaI or LaBr3)
  - NaI is low-resolution workhorse of hand-held ID instrument type

- IdentiFINDER R300 (CZT)
  - Formerly called “Interceptor” or “nanoRaider”
  - Compact : Small crystal : poor efficiency

- ORTEC Detective, MicroDetective (HPGe)
  - Expensive and cumbersome
  - High-resolution provides best data

These are just a few examples of the wide variety of instruments that are out there.

Activity

- Could this steel door hide:
  - U-238
  - U-235
  - Pu-239

Approximate Steel as Iron (Fe)
For U-238 use 1001 keV
For U-235 use 186 keV
For Pu-239 use 414 keV

Summary

- A gamma-ray spectrum is:
  - A histogram of energy deposited in a detector
  - A ‘fingerprint’ for a particular radionuclide
- Shielding can reduce the intensity of peaks in a spectrum, especially at lower energies.
- HPGe detectors provide the sharpest picture in terms of gamma ray data
- Regarding moderation and ^{3}He detectors:
  - Too little and neutrons are too fast to be detected
  - Too much and neutrons may get absorbed before reaching the ^{3}He tube